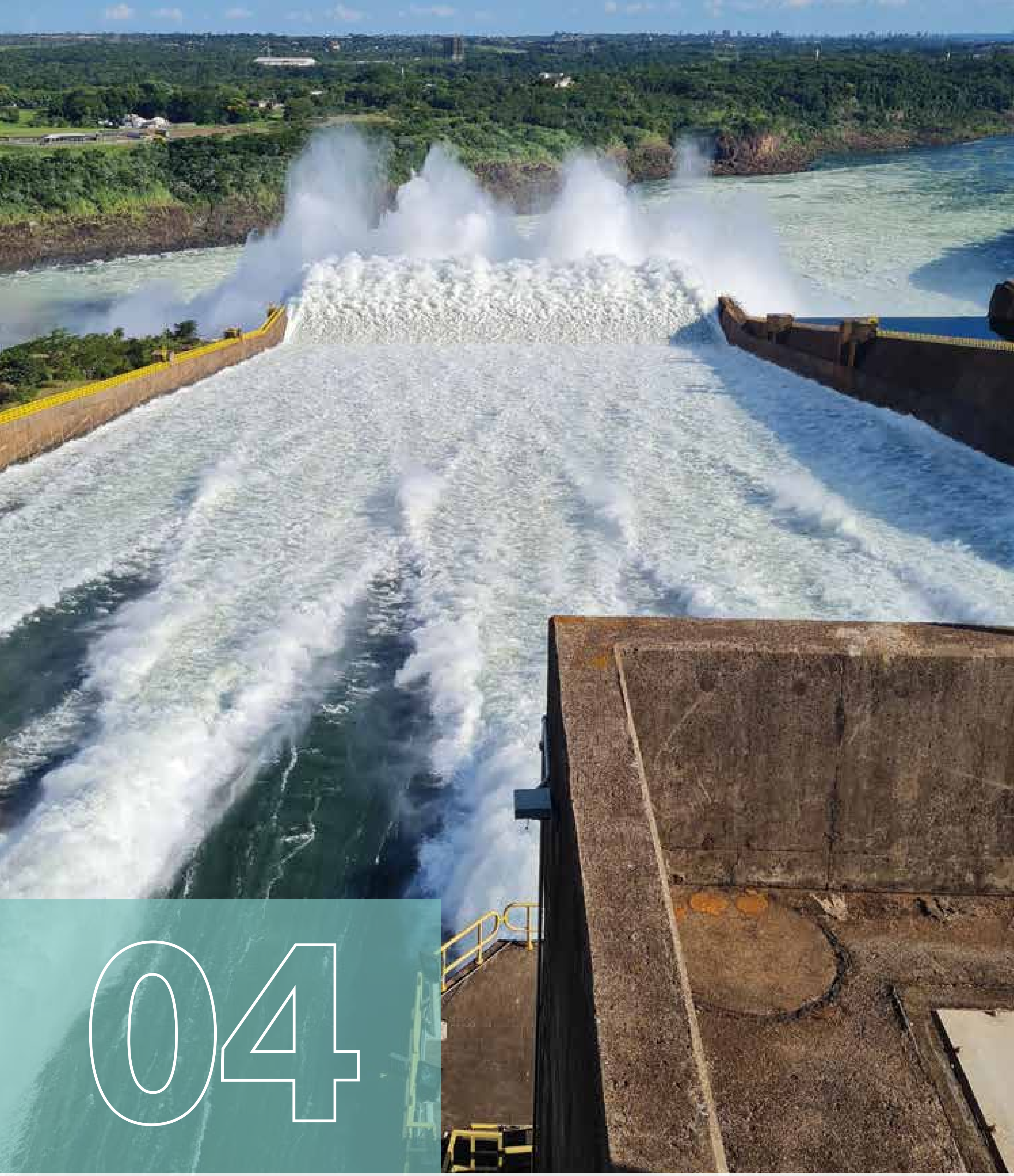


04

Opportunities for trade integration in specific clean energy technology value chains

4.1 Enabling clean energy access through electrification

A just clean energy transition is underpinned by universal electricity access. This is because electricity facilitates the use of renewables to cater to energy demand needs. For instance, in energy-deprived communities, ensuring electricity access can lead to a shift away from traditional and polluting energy sources like kerosene lamps and diesel generators.

Accelerating the process of electrification can also unlock a green transition in other sectors. Electrification, for instance, enables the deployment of electric vehicles as a substitute for internal combustion engine vehicles and allows for the adoption of electric heating systems in buildings.

Electricity access remains a pressing issue in many developing economies and LDCs. Nearly 760 million people worldwide were without electricity access in 2022. Some 608 million, or approximately 80 per cent of those without electricity access that year, were in sub-Saharan Africa (IEA, 2023j); and only 48 per cent of the population in sub-Saharan Africa has access to electricity.[1] The region uses the same amount of electricity as Spain despite having a population 18 times greater. An energy deficit on this scale impacts the possibilities for economic growth, trade integration and sustainable development.

Directly integrating communities without access to renewable electricity grids has been shown to be an effective strategy to promote energy access. According to IEA et al. (2021), the number of connections to renewable grids doubled between 2010 and 2019, with approximately one-third of this increase involving so-called "Tier 1" entrants, i.e., those from the lowest level of energy access. Nearly 105 million people have received energy access through decentralized solar grids in sub-Saharan Africa alone.

Clean energy is necessary both for climate transition and to solve a key trade-related infrastructure bottleneck faced by developing economies. Power generation is a key constraint for productive capacity, which inhibits trade and export potential.

An often-neglected question is how the development of renewable energy technologies can open opportunities for industrial development and value chain integration. Fulfilling such opportunities depends on a complex combination of factors, including competitive advantages, natural resource endowment, domestic supply-side capacity and the facilitatory trade and clean energy policies of developing economies seeking to enter specific clean energy value chains.

Another example of an initiative that can help generate spill over effects is the One Sun One World One Grid initiative (see Box 4.1). The initiative was established during the 26th session of the Conference of the Parties (COP26) in 2021 and is operated in partnership with the International Solar Alliance (Box 4.6) and the World Bank.

The subsequent sections will provide a deep dive into five renewable energy value chains that could be used to improve clean energy access through electrification and to improve development outcomes. Each section also discusses how Aid for Trade can help to seize opportunities in each technology.

Directly integrating communities without access to renewable electricity grids has been shown to be an effective strategy to promote energy access.

BOX 4.1 One Sun One World One Grid and the Green Grids Initiative

The Global Green Grids Initiative (GGI) was announced at the United Nations Climate Change Conference COP26 held in Glasgow in 2021.[2] Supported by Australia, France, India, the United Kingdom and the United States, the initiative seeks to create a more inter-connected global electricity grid to promote trade in energy from sun, wind and water across borders. This requires new transmission lines that cross borders and connect different time zones, forming a global ecosystem of interconnected renewable energy, combined with expanded and modernized national and regional grids.

To help realize this vision, an action agenda for global cooperation was developed through working groups of interested governments, regulators, financiers, institutions, companies, legislators and researchers.

The "One Sun One World One Grid" (OSOWOG)[3] initiative was launched by India and the United Kingdom during the same COP summit.[4] The aim of the "One Sun One World One Grid" initiative is to enable power access to nearly 140 economies through a common, cross-border grid that will help transfer clean and efficient solar power.

As per the OSOWOG Declaration,[5] the aims are to provide a common global framework for:

- "Investing in solar, wind, storage and other renewable energy generation in locations endowed with renewable resources for supporting a global grid."

- "Building long-distance cross-border transmission lines to connect renewable energy generators and demand centres across continents, underpinned by effective and mutually beneficial cross-border power trading arrangements."

- "Developing and deploying cutting edge techniques and technologies to modernise power systems and support green grids which can integrate billions of rooftop solar panels, wind turbines and storage systems."

- "Supporting the global transition to zero emission vehicles through incorporating the role of electric vehicles to help improve grid flexibility."

- "Attracting investment into solar mini-grids and off-grid systems to help vulnerable communities gain access to clean, affordable, and reliable energy without grid-access in their own areas, enhancing socio-economic development and a resilient power supply for all."

- "Developing innovative financial instruments, market structures, and facilitate financial and technical assistance to attract low-cost capital, including climate finance, for global solar grid infrastructure."

4.2 Wind energy value chains

Wind can be used to generate electricity through the conversion of kinetic energy produced by rotating turbine blades. It is one the fastest-growing renewable clean energy sources, with capacity expanding threefold over the past decade alone.

In 2022, wind accounted for 2100 terawatt-hours (TWh) of electricity generation, or nearly 25 per cent of all renewable production (IEA, 2023k). It is the second most adopted renewable technology after hydropower.

Wind is harnessed using turbines in either onshore or offshore locations. Onshore infrastructure is predominant, accounting for 93 per cent of all wind energy produced in 2021.

The scale of onshore adoption, coupled with major technological advancements, has led to steep cost declines. In fact, the weighted average levelized cost of electricity fell 68 per cent between 2010 and 2021 (IRENA, 2022a). This has made onshore wind generation competitive with electricity generated from fossil fuel sources. Following two consecutive years of decline, new global onshore wind installations are expected to recover significantly and reach almost 107 GW in 2023.

Offshore wind infrastructure is less diffused in comparison, generating approximately 7 per cent of all wind-based electricity in 2021 (IEA, 2022k). Rapid technological process has propelled deployment rates over recent years. Offshore capacity grew by 30 per cent year on year between 2010 and 2020. This momentum is set to continue, with estimates projecting that offshore wind may become the fastest growing clean energy source over the next four years, expanding by 240 per cent in capacity by 2026 (IEA, 2022e).

Offshore wind promises substantial electricity generation potential for coastal economies with optimal wind speeds of above 7 m/s. For instance, a study conducted by the World Bank of eight developing economies suggests that offshore wind turbines could produce 3.1 TW – a value that outstrips current electricity supply for these economies.[6] The study considers offshore areas within 200 kilometres of the coastline, with a fixed capacity of 1,016 GW and a floating capacity of 2,066 GW.

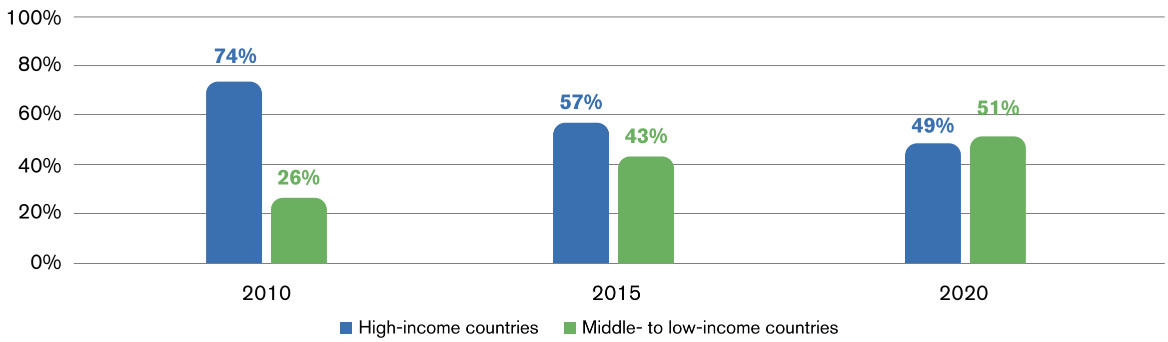
Falling costs and rapidly improving efficiency make wind a viable clean energy source for many developing economies and LDCs. Wind permits a larger scale of electricity generation, at a higher capacity factor, than any other clean energy source.

It is an ideal energy source for urban centres situated near optimal wind generation sites, which is the case for several African cities. A study by the International Finance Commission reveals that as much as 180,000 TWh of wind potential could be harnessed close to major African cities – enough to satisfy the continent's current energy demands 250 times over (Munyengeterwa and Whittaker, 2021).

High initial costs, limited local technical and knowledge capacity may initially hold back offshore turbines development. Experience with solar PV technology suggests, however, that costs could fall quickly once scale is achieved and supportive policy frameworks are crafted (GWEC and IRENA, 2013). In this context, adoption rates for both technologies have been growing over recent years.

Wind is one the fastest-growing renewable clean energy sources, with capacity expanding threefold over the past decade alone - it is the second most adopted renewable technology after hydropower.

FIGURE 4.1 Wind technology deployment across income groups



Source: UNCTAD (2023a).

Figure 4.1 illustrates this trend, concluding that disparities in wind energy deployment between income groups have tilted over recent years due to a faster rate of adoption in developing economies. The scale and magnitude of wind energy adoption is expected to grow further in coming years, with IEA forecasts estimating a tripling of generation capacity by 2030 and an eleven-fold increase by 2050 (IEA, 2021d).

The deployment of wind power is an important step toward ensuring electricity accessibility for developing economies and LDCs. Wind power is a scalable energy source that can expand rapidly, helping to extend electricity access to remote areas and provide continuous power supply to all communities. This could have a positive impact on economic activity, digital inclusion and thus trade potential.

How can Aid for Trade help to realize opportunities in the wind value chain?

Currently, Aid for Trade support is focused on the deployment of clean energy technology through the creation of wind farms. Significant scope exists to help expand developing-economy and LDC participation in all segments of this value chain. Aid for Trade can help developing economies and LDCs to participate in wind value chains in the following nodes of the value chain:

Minerals and metals: Critical minerals and metals necessary for wind power deployment include copper, nickel, zinc, aluminium and rare earth minerals such as neodymium and praseodymium (IEA, 2022h). These minerals are available in substantial quantities in developing economies and LDCs. The expected surge in the demand for these minerals and metals (in line with increased wind energy option) can be leveraged to enhance export potential. In this context, Aid for Trade can help economies to integrate into these supply chains by helping to harness investments into extraction sites, and the training of local stakeholders in safe and sustainable extraction methods. Box 4.4 provides an example of collaboration between Zambia and the UK to expand sustainable copper mining in order to improve export potential.

Goods: The deployment of wind energy will require the manufacturing and assembling of equipment such as towers, blades, bearings, generators and pumps (Energy Alternatives India, 2010). Ample opportunities for value chain integration exist for developing economies and LDCs. Aid for Trade can facilitate this process by providing support for research and development initiatives and capacity-building to help developing economies establish domestic manufacturing capabilities.

Services: The installation and operation of wind turbines is underpinned by a series of service activities. Wind farm developers provide essential value to the industry by planning, design and developing the structure of wind projects. Geotechnical experts ensure the suitability of projects by conducting feasibility studies on proposed wind farm sites. Transportation also plays a critical role, as wind power often involves technical and very specific modes of delivery. A technical paper presented by the delegation of the United Kingdom to the WTO also underlines the importance of ancillary services such as legal, financial, consultant and R&D inputs to the production of wind energy.[7] Aid for Trade can be leveraged to train a skilled workforce in system design, installation, maintenance and ancillary support to expand wind capacity. An example of such an initiative in Colombia is presented in Box 3.7.

Aid for Trade is already leveraging support for a number of infrastructural projects that improve electricity access – see Boxes 4.2, 4.3 and 4.4.

BOX 4.2 Supporting sustainable copper extraction in Zambia

Copper is utilized in the windings of electric generators in wind turbines and in the powerlines that connect the turbines to grids. The three-fold increase in wind generation capacity by 2030 therefore has the potential to rapidly increase the demand for this critical metal.

In 2021, Zambia was the seventh largest copper exporter in the world, catering to approximately 3.5 per cent of the world's copper demand. Copper forms a critical component of Zambia's export basket. In 2021, Zambia's earnings from the sale of copper were valued at US$ 7.7 billion, or 75 per cent of its annual export value. The importance of consolidating the benefits of copper mining to improve domestic economy fortunes has been underlined in Zambia's "National Trade Policy", "Industrial Policy", "National Export Strategy" and the "8th National Development Plan", documents referenced by Zambia in its response to the 2022 Aid for Trade M&E questionnaire.

The development of Zambia's copper industry is a key priority in the "Green Growth Compact" agreement signed between the United Kingdom and Zambia in 2021.[8] The bilateral compact identifies targets for delivering US$ 3 billion of aid and investments for renewable energy, urban planning and trade connectivity. Through the Compact, the United Kingdom and Zambia look to double bilateral trade volumes and strengthen coordination between UK and Zambian business communities.

As part of the Compact, the two economies will also sign a Memorandum of Understanding on critical minerals, laying the foundation for further UK support for the responsible mining of copper and other metals essential to the global clean energy transition. The United Kingdom will also look to leverage public and private investment worth US$ 210 million in Zambia's Mimbula Copper Mine. This investment will help to expand production, boost exports and growth potential for the Zambian economy.[9]

BOX 4.3 Lake Turkana Wind Power Project (LTWP)

Kenya is a global leader in renewable energy and is on track to transition fully to clean energy by 2030. Renewable energy currently accounts for 73 per cent of Kenya's installed power generation capacity, while 90 per cent of electricity in use is from green sources, among them geothermal, wind, solar and hydro-electric installations.

A flagship project for the Kenyan government is the Lake Turkana Wind Power project, which hosts Africa's largest wind power farm. The project is Kenya's largest single public-private sector investment and is financed by the Government of Kenya, together with an international consortium of lenders, including the African Development Bank, the Danish Investment Fund for Developing Countries, the Finnish Fund for Industrial Cooperation, and Norfund Investments.

The project comprises 365 wind turbines, each with a capacity of 850 kW, a high-voltage substation that is connected to the Kenyan national grid through a 428 km-long transmission line, and the construction of more than 200 km of road to transport equipment to the remote site. The wind farm provides reliable, low-cost energy to Kenya's national grid (about 17 per cent of the economy's installed capacity). Beneficiaries of the generated electricity includes rural and urban communities. The LTWP also serves energy to industrial parks around Kenya, which includes firms oriented toward the export market.

BOX 4.4 Aid for Trade in action: Taiba N'Diaye Windfarm

Spanning an area of approximately 20 square kilometres, the Taiba N'Diaye Windfarm is located about 70 kilometres northeast of the Senegalese capital, Dakar, near the village of Taiba N'Diaye. It is the first wind project in Senegal and the largest wind project in West Africa in terms of installed capacity. The project was initiated as part of Senegal's energy diversification plan, aiming to increase the proportion of renewables in the domestic energy mix and bolster energy security.

The Taiba N'Diaye Windfarm was highlighted by Senegal in the 2022 Aid for Trade M&E exercise as a development project in line with Senegal's aim to become a regional spearhead for clean energy adoption. The windfarm forms a key component of the "Plan Sénégal Emergent" development plan. The windfarm consists of turbines equipped with large rotor blades to catch the strong coastal winds that sweep across the region. It boasts an impressive total capacity of around 150 to 200 MW and contributes significantly to Senegal's power generation capacity. The windfarm is expected to contribute to expand Senegal's total energy capacity by 15 per cent and providing power for over 2 million people.

Energy generation through this windfarm provides several trade benefits. First, it provides a reliable energy source for industries and businesses which require a continuous power supply for production. Second, it aligns domestic production with international sustainability and environmental standards, making Senegalese products and services more attractive to environmentally conscious international markets. Increased export competitiveness could lead to improved trade opportunities and access to international markets for Senegalese goods and services.

The enhancement of regional infrastructure to support the windfarm is also expected to wield diffused trade benefits. Senegal is the third-largest mango exporter in West Africa, and the region surrounding the windfarm is home to some of the largest mango producers. According to USAID (one of the stakeholders in the project), the feeder roads built for the windfarm have optimized farmers' access to regional mango groves, leading to reduced crop losses, increased area incomes and expanded export opportunity.[10]

4.3 Solar photovoltaic value chains

Solar PV technologies use solar panels to convert sunlight into electricity. In 2022, solar PV produced 1300 TWh of electricity, accounting for approximately 4.5 per cent of global electricity generation and 13 per cent of renewable electricity generation respectively (IEA, 2023k). Rising adoption rates and declining costs will place solar PV as the main electricity energy source by 2050.

Adoption rates have accelerated over recent years, with global installed capacity rising 16-fold over the past decade alone. Rapid solar PV deployment in developing economies played a key role in this context (see Figure 4.2). The share of developing economies and LDCs in solar capacity expanded considerably between 2010 and 2020, growing from 4 per cent in 2010 to 52 per cent in 2020.

These expansions are being driven by increased solar adoption rates in China, which has emerged as the global leader in solar installation capacity. In 2022, China accounted for almost half of all new renewable power capacity worldwide (IEA, 2023g). In recent years, China has been joined by economies such as Brazil, India, Thailand and Viet Nam, which are also accelerating the expansion of their solar PV capacity (UNCTAD, 2023a).

Many other developing economies and LDCs could also derive substantial benefits from their own solar PV deployment due to geographical advantages in terms of sunlight. In some locations, year-round sunshine, intense sunlight and limited cloud cover allows installed panels give significant electricity generation potential. World Bank estimates reveal that economies in the Middle East, North Africa, sub-Saharan Africa and the Pacific islands belt possess some of the best climactic conditions to derive maximal solar PV efficiency (ESMAP, 2020).

Adoption gains are being driven by steep falls in the levelized cost of energy for solar PV. Technological advancements, coupled with the growing scale of production, have driven installation costs down from US$ 1.9 per watt in 2010 to approximately US$ 0.2 per watt in 2020.

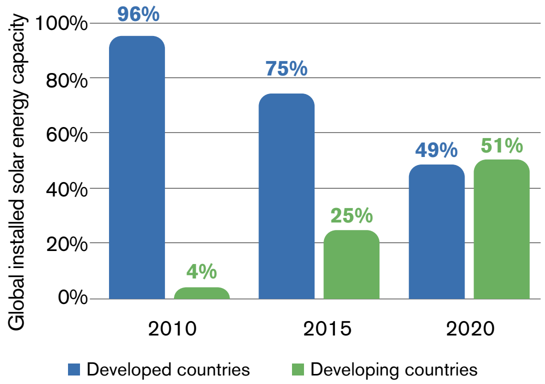
As a result, solar PV has gone from being more than twice as costly as the most expensive fossil fuel option to becoming cost-competitive with the cheapest fossil fuel sources available (IRENA, 2021b). The rapid declines in the cost of solar PV and the associated rise in solar PV trade can be seen in Figure 4.3.

The diffusion of solar PV for energy generation has been recognized as an important step to ensure electricity accessibility for developing economies and LDCs. As highlighted in Section 4.1, nearly 105 million people have received energy access through decentralized solar grids in sub-Saharan Africa alone.

Solar PV is an easily installable energy source that that can help to extend electricity access to remote areas and ensure continuous power supply. This could have a positive impact on economic activity, digital inclusion and, therefore, trade potential. Box 4.5 provides an example of how electricity access can improve economic potential, through the provision of solar mills in Vanuatu.

Deploying solar PV farms may also open new opportunities for electricity exports. In 2019, Morocco switched from being a net importer of electricity (with net imports of 3,374 GWh) to a net exporter, with net exports of 928 GWh. Morocco now ranks fourth globally in electricity generation from thermal solar technologies. Its electricity system is interconnected with Algeria and Spain, making Morocco the only North African economy with a power cable linking it to the European grid (GIZ, IRENA and BMZ, 2020). An investment consortium is currently examining the possibility of connecting Morocco and the United Kingdom through undersea power cables (Reuters, 2023).

FIGURE 4.2 Installed solar PV capacity, split by development category



Source: UNCTAD (2023a).

SOLAR PV INSTALLATION COSTS

in 2010

US$1.9 per watt

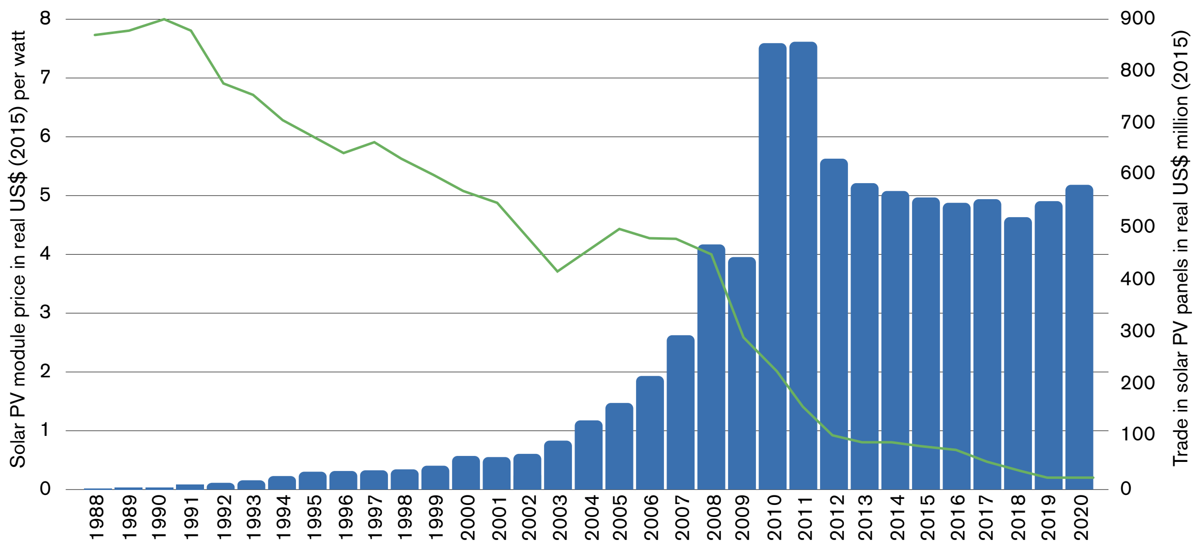
in 2020

US$0.2 per watt

due to technological advancements and the growing scale of production.

The rate of solar PV deployment is expected to increase globally over coming years. IEA research indicates that solar PV is forecast to account for 60 per cent of the increase in global renewable capacity in 2022. More than US$ 1 billion per day of investments is expected to be funnelled into solar investments in 2023, increasing solar investments to more than oil investments for the first time in history (IEA, 2023a). This would provide opportunities for developing economies and LDCs to integrate into value chains.

FIGURE 4.3 Price and trade in solar PV panels



Source: WTO (2022b).

BOX 4.5 Aid for Trade in action: solar mills in Vanuatu

Imported refined petroleum accounts for 72 per cent of Vanuatu's total energy supply. This dependency has a disproportionate economic impact on Vanuatu, as the archipelago's geographical remoteness and dispersed population contributes to marginally higher fuel import costs. As a result, many households rely on an expensive and often unreliable electricity supply to support basic household needs.

Intermittent electricity access has hampered effective capital proliferation in the agricultural sector, which is the primary export earner. It has meant that farmers must often employ manual processes for gathering agricultural produce.

To address this infrastructural constraint, the Australian Government partnered with "Village Infrastructure Angels Australia" to provide solar energy solutions to 3,000 households in Vanuatu.[11] Australian assistance has also helped supply solar agricultural mills to 30 of the economy's 60 inhabited islands This project was reported in the 2022 Aid for Trade M&E questionnaire.

The deployment of solar solutions has been shown to have led to several benefits. It has helped to reduce reliance on fossil fuels and boosted rural incomes. Furthermore, the use of solar power has helped citizens diversify their production base, with more spending time on activities such as basket weaving. It has also helped to improve added value, with many farmers making new products such as vacuum-packed cassava flour and coconut oil, which have a higher profit margin compared to raw crops in export markets.

In addition, more reliable electricity provides better lighting for children to study by at night and will help communities build educational capacity in the long run.

BOX 4.6 International Solar Alliance (ISA) and One Sun One World One Grid

The International Solar Alliance (ISA)[12] was conceived by India and France to mobilize efforts against climate change. It was launched in Paris, in 2015 on the margins of COP21. As of 2022, 101 economies are signatories to the ISA Framework Agreement.

The objective of the ISA is to develop and deploy cost-effective solar solutions to help member economies develop low-carbon growth trajectories. The alliance is guided by its "Towards 1,000" strategy, which aims to mobilise US$ 1 trillion of investment in solar energy solutions by 2030, while delivering energy access to 1,000 million people using clean energy solutions, resulting in the installation of 1,000 GW of solar energy capacity.

The ISA places particular focus on delivering assistance to LDCs and small-island developing states. To this end, the ISA focuses on four priority areas to maximize solar deployment: analytics and advocacy; capacity building; programmatic support; and readiness and enabling activities.

ISA partners include development finance institutions and public- and private-sector organizations.

BOX 4.7 Supporting artisanal bauxite mining in Guinea-Bissau

In the 2022 Aid for Trade M&E exercise, Guinea-Bissau highlighted the "Terra-Ranka" development strategy[13] as an example of a national plan that outlined export objectives. In this strategy, the mining sector was underlined as one of the four sectors with substantial export potential. The strategy looked to promote small-scale mining, particularly in the context of phosphates and bauxites.

Bauxite has substantial clean energy value, as it is a sedimentary rock used to extract aluminium. The demand for this metal is expected to double between 2020 and 2040. Bauxite is especially required in the processing of solar PV frames, and the World Bank estimates that by 2050, around 87 per cent of all aluminium requirements for energy technologies will be for solar PV manufacturing (Hund et al., 2020).

According to AfDB estimates, Guinea-Bissau holds around 160 million metric tonnes of bauxite deposits. These deposits are part of the Fouta Djallon-Mandingo bauxite province, which makes up almost half of the world's total bauxite resources. Establishing a framework that promotes sustainable extraction could therefore help to expand export potential rapidly.

The Terra-Ranka development strategy is working towards this objective by introducing reforms that promote investments and the upskilling of workers to help expand production. To this end, Guinea-Bissau has received assistance from the AfDB through a transition support facility catering to artisanal and small mining.

Through this project, the AfDB intends to support the Terra-Ranka strategy by formalizing artisanal and small-scale mining stakeholders to create jobs and improve the socio-economy, improving the capacity of regulatory institutions to enforce mining laws and regulations, and facilitating project coordination and management.[14]

The AfDB expects this project to have a positive impact on the livelihoods of more than 10,000 people directly involved in the artisanal and small-scale mining subsector. The project will also lead directly to training for more than 500 mining regulatory officials to diffuse best mining and investment practices. Overall, this is expected to trigger export avenues, wealth creation opportunities and decent employment.

How can Aid for Trade help unlock opportunities in the solar value chain?

Aid for Trade can be leveraged to support solar development in various ways. Currently, as is the case for wind energy, Aid for Trade financing has been generally focused on the deployment of the clean energy technology. Possibilities for developing economies and LDCs participation in solar PV include:

Minerals and metals: Copper, aluminium and silver are some examples of metals and minerals essential to the manufacturing of solar PV equipment (IEA, 2022h). The surge in their demand (in line with the expected increase in solar PV adoption rates) can be used as an opportunity to enhance the export potential of developing economies and LDCs endowed with these resources. Aid for Trade can help capture this opportunity by harnessing capital (in the form of concessional and/or blended financing) to support sustainable extraction for exports. Aid for Trade can also be used to improve supply-side capacity to ensure that the economy can leverage resources productively to maximize welfare benefits. Box 4.7 provides an example of such Aid for Trade collaboration in Guinea-Bissau.

Goods: A few examples of components required to assemble solar PV include semiconductors, integrated circuits, wafers, cells electric generators, transformers, transistors and static converters. Production also requires supplementary products, such as concrete, plastic, polymers and corrugated board (WTO and IRENA, 2021). As highlighted in Section 3, a few economies, most notably China, have positioned themselves as important nodes in the solar PV value chain. For instance, components such as solar wafers, cells and account for around 10 per cent and 5 per cent respectively of Malaysia and Viet Nam's trade surpluses. Aid for Trade can facilitate this process by supporting research and capacity building initiatives that help spotlight the manufacturing opportunities in developing economies and LDCs. The research conducted by Sustainable Energy for All (see Box 3.4) is an example of such an activity.

Services: The operation of centralized or decentralized grids is underpinned by a series of services activities that have been highlighted in Section 3.3. Aid for Trade can be leveraged to train a skilled workforce in system design, installation, maintenance and ancillary support to expand solar PV capacity. Aid for Trade can also be used to promote circular economy mechanisms, and can enhance the value of end-of-life service sector operations (see Box 4.8).

BOX 4.8 Solibrium: a solar service provider

Solibrium[15] is a social enterprise based in Western Kenya that provides off-grid electricity solutions to households and business, through a programme with pay-as-you-go service options.

Customers are provided with 24-hour electricity access by means of solar kits integrated to software systems that can track generation capacity and customer needs. Solibrium works not only as a distributor of solar home systems, but offers a holistic and complete sales, distribution and repair ecosystem to rural solar users.

Solibrium is also in the process of introducing an economically viable business model for the recycling of solar kit components. The project, titled "Resource Efficiency and Waste Management for Off-grid Solar products", is being implemented in partnership with the Swiss Agency for Development and Cooperation (SDC).

As a next step, Solibrium intends to develop a solar waste tracking tool to identify types, quantities and locations of products to guide future waste management planning. Through this initiative, Solibrium aims to become a regional leader in the recycling and refurbishing of solar kits to extend product lifespan.

4.4 Hydropower value chains

Hydropower, which involves the production of kinetic energy through the movement of flowing water, is an established source of renewable power worldwide. In 2021, global hydropower capacity was estimated at around 4,300 TWh, accounting for nearly 45 per cent of total annual renewable electricity capacity (IEA, 2023c). Globally, nearly 800 million people rely on hydropower as a cost-effective and dependable source of electricity (IEA, 2023d).

Hydropower can be generated through various means. For instance, run-of-the-river systems harness the natural water flow of rivers to generate electricity. Impoundment systems (for instance by using dams) store and release water for power. Pumped storage involves storing of water that is transported uphill and released in cycles for power generation. Recent innovations have also unlocked the capacity to produce scalable electricity from marine water bodies, by tapping into the power generated through tidal and wave patterns (IRENA, 2023b).

Hydropower has significant potential for further development given that it is already very present in the energy mix of developing economies. IEA research indicates that hydropower supplies more than 50 per cent of total electricity generation in 28 developing economies (IEA, 2023d). Furthermore, 85 per cent of new hydropower plants constructed over the past 15 years are in developing markets. Large hydropower projects also contribute to agricultural development in these economies, by providing the water management infrastructure necessary to secure and expand crop cultivation.

Hydropower investments are prominent in the renewable energy investments being made by China in the context of the Belt and Road Initiative (BRI). An example is the Cambodia Upper Tatay Hydropower Station, bolstered

BOX 4.9 ADB assistance to expand Bhutan's hydropower export capacity

Hydropower generation plays a crucial role in Bhutan's economy. The activity accounts for approximately 25 per cent of annual GDP and contributes to approximately 63 per cent percent of Bhutan's total exports. However, the full potential of hydropower for Bhutan's development remains untapped. According to the Asian Development Bank (ADB), Bhutan is currently only generating about 9-10 per cent of its 26,760 MW hydropower generation capacity.

Since 2008, the ADB and the Government of Bhutan have been collaborating in two "Green Development Projects" to fulfil this potential. These projects aim to enhance Bhutan's clean energy export capacity, while supporting social services and electricity access for the poor.

Under the first Green Development Project,[16] which was in operation from 2008 to 2014, the ADB helped Bhutan deploy the Dagachhu hydropower plant. This plant helped to export power from Bhutan to India through the existing grid[17] and provided electricity access to 8,767 households.

The Second Green Power Development project commenced in 2014.[18] The project outputs include operation of the 118 MW run-of-the-river Nikachhu hydropower plant and its associated transmission lines. This second phase will generate 903,490 MWh annually, on average, and a large share of the power generated is expected to be exported outside Bhutan. The work on this phase is expected to be completed by December 2023.

by Chinese investment, aimed at expanding Cambodia's reliable source of clean energy.[19]

Aid for Trade could play a key role in supporting the deployment of effective hydropower capacity across developing economies. For instance, Aid for Trade can be harnessed for large-scale infrastructural projects that provide direct trade benefits. Box 4.9 provides an example of such a scenario in Bhutan.

How can Aid for Trade help to unlock opportunities in the hydropower value chain?

Aid for Trade can help to leverage possible value chain integration opportunities for developing economies and LDCs. These for instance include:

Minerals and metals: Minerals required for the primary installation and deployment of hydropower include copper (for electrical wiring and conductors in generators), aluminium (for transmission lines) and rare earth minerals such as neodymium and dysprosium (for power generation). As discussed in Section 3.1, many developing economies and LDCs have well-established domestic sectors that can serve the mineral demands of a potential hydropower expansion (see, for example, Box 4.4 on copper extraction in Zambia).

Goods: The deployment of hydropower requires a wide array of equipment and components that could potentially be manufactured in developing economies and LDCs. For instance, in the context of large-scale impoundment systems, the required goods include hydroelectric turbines, electric generators, transformers and hydraulic gates and values.

Services: Institutions can help to transfer knowledge and expertise to support the development and maintenance of domestic manufacturing capabilities in the hydropower sector.

4.5 Hydrogen value chains

Recent technological advances have generated considerable interest in the use of hydrogen as a direct clean energy source for activities such as iron, steel and chemical production, where decarbonizing through electrification is not possible or uneconomic (Nault, 2022).

The association of hydrogen with scalable clean energy generation is a relatively new phenomenon. Until recently, hydrogen was an input in the production process of steel, ammonia, methanol and petroleum products. In the petroleum sector, hydrogen is an essential element in hydrocracking – a process to separate petroleum products in refineries (EIA, 2013). For this purpose, hydrogen was generated using natural gas or other fossil fuels in a highly emission-intensive production. Annual CO_2 emissions through traditional hydrogen production were estimated at 1,100-1,300 Mt in 2022, roughly equivalent in size to Japan's annual CO_2 emissions (IEA, 2022d).[20]

The cleanest hydrogen, in terms of associated GHG emissions, "green hydrogen", can be produced through the process of electrolysis, whereby water is split into its component molecules, including hydrogen, using an electrolyser driven by clean, renewable electricity. The next cleanest alternative is the production of "blue hydrogen", that is, the production of hydrogen using fossil fuels or natural gas (through non-electrolysis reforming methods) but with carbon capture, utilization and storage (CCUS) technologies used to capture and store the CO_2 produced.

BOX 4.10 Colombia's hydrogen road map

Colombia has pledged to reduce GHG emissions by 51 per cent by 2030, compared to 2010 levels. In pursuit of this plan, it has initiated several policy steps to support a clean energy transition. The "Hydrogen Road Map" is an example of such efforts. The Road Map was highlighted by Colombia in its response to the 2022 Aid for Trade M&E exercise.

The aim of the Hydrogen Road Map is to increase volumes of hydrogen production and to help capture export opportunities through trade with regional economies. It was prepared in conjunction with the Inter-American Development Bank and the United Kingdom.

The Hydrogen Road Map projects that Colombia has the capacity to produce between 3.2 and 5.8 Mt of green hydrogen by 2050 if available renewable energy potential is sufficiently captured. This leaves substantial room for export potential, as the domestic demand for hydrogen in Colombia is expected to reach between 1.6 and 1.8 Mt by 2050. Three major export economies or regions have been identified in this regard. The Road Map notes that Asia, particularly Japan, could be a major destination market for exports. The European Union and the United States have also been identified as possible high-value destinations in the near future.

The Hydrogen Road Map also identifies the regulatory changes needed to promote and deploy hydrogen-based technology. It would require the production of blue hydrogen during the initial phase of technology deployment to ensure a gradual transition away from the economy's mining and gas sectors, as a means to minimize social effects. The switch to green hydrogen could occur within 15 to 20 years, when electrolyser technology becomes adequately competitive to substitute production.

In cooperation with national educational institutions, Colombia will also look to develop a hydrogen technology and knowledge transfer plan with universities and companies. Financing programmes for technical and vocational training will also be institutionalized to ensure that the domestic service economy is adequately prepared to cater to the hydrogen economy (Energy Transitions Commission, 2021).

The rapid deployment of green hydrogen is currently hindered by its higher cost of production when compared to production alternatives. The World Bank estimates that it costs approximately US$ 4-5 to produce a kilogramme of hydrogen as of 2023 (IEA, 2023i). This is around two to three times higher than the cost of producing hydrogen using fossil fuels. As a result, less than 1 Mt of cleaner hydrogen was produced in 2021, or roughly 1 per cent of annual hydrogen output (IEA, 2022c). Green hydrogen production is negligible at present, with cleaner hydrogen mostly derived from plants using fossil fuels with CCUS technologies.

> The expansion of clean hydrogen could give substantial impetus to the net zero transition.

Green hydrogen is expected to play a greater role in coming years, as production costs are projected to become cheaper than alternates. This is due to learning effects that enhance technology performance and production processes, as well as economies of scale (Gielen, Lawal and Rocha, 2023). The IEA estimates that by 2030, the production of cleaner hydrogen (both

BOX 4.11 Green hydrogen production in Namibia

Namibia is emerging as a player in the hydrogen market, with ambitions of becoming the leading exporter of green hydrogen in Africa.[21] During COP27, Namibia's Green Hydrogen Council launched a strategy to help steer the domestic economy towards hydrogen goals. However, the Council noted that, although Namibia has favourable renewable energy conditions, it lacks the adequate supply-side infrastructure and sectoral capacity to maximize trading potential.

To this end, a joint communique of intent was signed between Namibia and the German Government in 2022 to promote cooperation in the hydrogen sector and assist in infrastructure development.[22] A key objective of this partnership is to promote Namibia's potential to produce green hydrogen for domestic use as well as for export to Germany and other markets. Strategies to serve this objective include:

- Development of a "National Green Hydrogen Strategy" in Namibia.
- Establishment of strategic pilot plants to assess scalability.
- Allocation of 200 scholarships for Namibians to help domestic technical capacity.
- Formulation of market access partnerships to improve trade facilitation.
- Fund the establishment of a "Green Hydrogen Institute" in Namibia.

In August 2022, the Namibian government began construction of a hydrogen demonstration lab in the Erongo Region. The hub is expected to be in operation by 2024 and will initially produce green hydrogen for local energy use in trucks, locomotives and port equipment. The hub will also include a training and education centre to provide local Namibians with necessary knowledge and skills.

"green" and "blue") could reach 16-24 Mt per year, from a base of 1 Mt per year in 2021 (IEA, 2023i).

The expansion of clean hydrogen could give substantial impetus to the net zero transition. This is because it can function as an effective substitute for liquid petroleum, which is currently used as the predominant energy source for power generation, industrial processing and transport. The IEA estimates that growing demand for clean hydrogen could help reduce CO_2 emissions by 60 Gt in 2050. This is equivalent to approximately 6 per cent of the greenhouse gas emissions reductions required per the Paris Agreement over the period 2021-2050 (IEA, 2022d).

Cross-border trade of hydrogen is often perceived as a risky venture due to the element's highly combustible nature. Improvements in the capacity to safely handle and store hydrogen promise to greatly improve hydrogen portability over longer distances. Better storage methods also allow for green hydrogen to be stored for longer periods of time. The ability to trade hydrogen through alternative carriers such as ammonia

BOX 4.12 Australia and India set up a Green Hydrogen Task Force

India is emerging as a key player in the electrolyser manufacturing space. In January 2023, India approved the "National Green Hydrogen Mission",[23] with a target to achieve green hydrogen production of 5 metric tonnes per annum by 2030. The objective is the creation of export opportunities in the green hydrogen value chain, particularly through the development of indigenous manufacturing capacity.

Australia has also been prioritizing the development of electrolyser capacity. Through the "Hydrogen Headstart" initiative[24] implemented in 2023, Australia has allocated US$ 2 billion to provide revenue support for investment in renewable hydrogen production.

In March 2023, Australia and India agreed to set up a "Green Hydrogen Task Force" to develop green hydrogen resources jointly. The agreement notes that the initial focus area of the task force would be to expand the production of equipment such as electrolysers and fuel cells. Strategies to achieve this objective include:

- Identifying strengths and gaps in industry and resource endowments and skills in each economy.
- Examining specific opportunities on how enabling infrastructure, standards and regulations can be deployed to maximize hydrogen opportunities.
- Researching areas or projects that may benefit from private sector investments.

could also help improve tradability. Research notes that in addition to its role as a fertilizer, ammonia (produced using clean hydrogen) can be used as an effective fuel for stationary power and as a transport fuel, particularly in the maritime industry (IRENA and AEA, 2022).

In this context, green hydrogen produced in regions with abundant solar and wind capacity could be transported elsewhere, paving the way for a clean global hydrogen energy trade. The trade would be based on exports between regions possessing abundant low-cost renewable clean energy production to those with limited production options (IEA, 2021f).

Demand for green hydrogen is expected to increase significantly in the next 30 years as the transition towards a net zero economy advances. The Energy Transitions Commission (ETC)[25] estimates that 500 to 800 Mt/year of hydrogen (in any form) – a four to six-fold increase from current demand levels – will be needed in 2050 (Energy Transitions Commission, 2021). Sectors with high potential in the long term include steel production, shipping, aviation and the power sector. In other sectors, such as domestic heating, high temperature heat applications, plastics manufacturing and heavy-duty transport, hydrogen is seen as a possible alternative to direct electrification or other decarbonization options. Potential short-term but transitional uses of hydrogen to reduce emissions include the co-firing of ammonia or hydrogen in conventional power plants or blending with natural gas.

Developing economies and LDCs are already looking at expanding their production of clean hydrogen production. Economies as diverse as Brazil, China, Colombia, Costa Rica, India, Indonesia, Malaysia, Namibia, Nepal, Morocco, South Africa and Thailand have all made commitments towards domestic hydrogen capacity development.

Developing the hydrogen sector could help to usher in a domestic clean energy transition by providing cleaner alternatives to sectors which are dependent on non-electric sources of power. Hydrogen can also be used as a storage infrastructure for energy produced through renewables. It could also help to improve export diversification potential, as hydrogen created through domestically available renewable sources could be traded as a commodity.

How can Aid for Trade help unlock opportunities in the hydrogen value chain?

Collaboration between Aid for Trade stakeholders to build hydrogen capacity is already evident on a global scale – see, for instance, Box 4.10 on Colombia's "Hydrogen Road Map" and Box 4.11 on collaboration between Germany and Namibia to build domestic hydrogen supply-side capacity.

Possibilities for using Aid for Trade to help developing economies and LDCs participate in hydrogen GVC include:

Minerals and metals: The manufacture of electrolysers for green hydrogen production requires minerals and metals such as nickel, platinum, aluminium, graphite and iridium. Aid for Trade can be directed towards expanding supply-side capacity to enhance sustainable export potential. Aid for Trade can also be used to help establish policies that foster sustainable extraction and assist local stakeholders in implementing safe and environmentally responsible production methods.

Goods: Aid for Trade can help to facilitate technology transfer partnerships that help to expand domestic manufacturing capacity in developing economies. Aid can also be leveraged to help enhance market access and create adequate regulatory conditions for a cross-border hydrogen trade. The establishment of the India-Australia Green Hydrogen Task Force is an example of such a partnership that helps build manufacturing (electrolyser) capacity (see Box 4.12).

Services: Aid for Trade can help to implement training for workforces in system design, installation and maintenance of equipment such as electrolysers and supporting the growth of local service providers.

4.6 Nuclear power value chains

The use of nuclear power continues to grow, albeit more slowly than other clean energy sources. Nuclear energy provides 10 per cent of the electricity produced worldwide and more than 25 per cent of global clean electricity. Nuclear power capacity is expected to double from 413 GW in early 2022 to 812 GW in 2050 (IEA, 2023f). According to the IEA, growth in nuclear power is expected to accelerate in the coming years, reflecting strengthened policy support in leading markets and brighter prospects for small modular reactors. Developing economies are expected to account for more than 90 per cent of global growth, with China set to become the leading nuclear power producer by 2030.

The importance of nuclear power for a clean energy transition was recognized at COP28. The COP28 outcome document included nuclear power among the key clean energy solutions (see Box 1.2).

In addition, more than 20 economies from four continents launched the "Declaration to Triple Nuclear Energy" at COP28. This declaration calls for economies to work together to advance a goal of tripling nuclear energy capacity globally by 2050, and invites shareholders of international financial institutions to encourage the inclusion of nuclear energy in energy lending policies.[26] The declaration, and the references to nuclear power in the outcome document, are indicative of rising interest in establishing nuclear energy as a clean alternative to fossil fuel production. New breakthroughs in the production of energy through nuclear fusion may also help to deliver a newer and more source of clean energy in the long run (CNN, 2023).

In 2020, the number of International Atomic Energy Agency (IAEA) member states operating nuclear power plants increased to 32, after Belarus and the United Arab Emirates connected reactors to the national grid. Of these operating economies, 19 have projects in place to expand their nuclear power capacity. Around 30 newcomer economies are embarking on, or considering, nuclear power.

Some developing economies have considerably advanced in the construction of their first nuclear power plants (IAEA, 2021a). For instance, Bangladesh has made substantial progress in creating infrastructure for nuclear generation capacity. Two reactors, built with assistance from the Russian Federation are expected to become operational by 2024 to provide 9 per cent of Bangladesh's electricity supply (Fisher, 2021).

Several African economies, including Ghana, Kenya, Namibia, Nigeria, South Africa, Sudan, Tanzania, Uganda and Zambia, have in recent years expressed significant interest in developing new nuclear plants (Nordhaus and Lloyd, 2022). Box 4.13 provides a brief overview of emerging nuclear power projects in the African continent developed through cooperation with Russia.

Nuclear capacity can complement the domestic energy mix, ensuring that the gaps created due to the intermitted nature of renewable energy do not cause disruptions to the grid supply of electricity. Furthermore, nuclear power projects can stimulate economic activity and employment across many sectors, including construction, manufacturing, services and agriculture.

Small nuclear reactors are an area of innovation that can help diffuse nuclear technology in developing economies. They are essentially advanced reactors that produce electricity of up to 300 MW per module (IAEA, 2021b). Given the smaller reactor sizes and simplified design, these facilities could be easier to finance, construct and operate. Small nuclear reactors are nearing commercial deployment in several economies in Europe, the Middle East, Africa and Southeast Asia. Investment in small nuclear reactors and other advanced reactors is being encouraged through public-private partnerships.

International trade can play a crucial role in the diffusion of nuclear technology. As of 2022, trade in nuclear reactors, nuclear fuel, machinery and apparatus amounted to US$ 2.8 billion. Trade can facilitate the cross-border flow of nuclear equipment such as reactors, rods fuel cycle facilities and casks between economies. Additionally, trade can also play a role in the diffusion of services and technology required to develop domestic nuclear capabilities.

From a trade policy perspective, the diffusion of nuclear technology Is highly regulated due to the dual use potential of such technology and national security concerns.

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BOX 4.13 Developing nuclear power generation in Africa with Russian assistance

Russia and Egypt are cooperating on a nuclear plant, to be constructed in partnership with Russia's State Nuclear Energy Corporation (Rosatom) and Egypt, in the Egyptian coastal town of El Dabaa.[27] The site for the plant has been approved by the International Atomic Energy Agency (IAEA) and is set to house four nuclear reactors capable of producing nearly 5 GW of energy. The first unit is expected to begin commercial operations in 2026 while the remaining three reactors are scheduled for commissioning by 2029.

Russia, through Rosatom, is also involved in the development of nuclear potential in Uganda. Endowed with a domestic supply of uranium, Uganda is currently in engagement with International Atomic Energy Agency (IAEA) to commence nuclear power generation capacity by 2032.[28] Russia plans to help Uganda with development of nuclear infrastructure and production and application of radioisotopes for industrial use.

Russia is also assisting Morocco in its efforts to established nuclear generation capacity by 2030. Morocco is endowed with substantial phosphate and uranium reserves which are vital raw materials required for power generation through nuclear technologies. As per a nuclear cooperation agreement signed in 2022, Russia will assist Morocco in the creation and improvement of nuclear energy infrastructure, the design and construction of nuclear reactors, as well as water desalination plants and elementary particle accelerators.

Russia has also signed exploratory agreements with Tanzania, Rwanda and Zimbabwe.

Other African states interested in developing nuclear capacity include Ghana, Nigeria, Sudan, Rwanda and Zambia.

BOX 4.14 Developing a low-enriched uranium fuel bank in Kazakhstan

Kazakhstan is the world's largest producer of uranium. Production of uranium accounts for 43 per cent of global production and 22 per cent of the cross-border trade in uranium.[29]

In 2015, Kazakhstan approved an agreement with the International Atomic Energy Agency (IAEA) to establish a low-enriched uranium (LEU) fuel bank at the Ulba Metallurgical Plant in Oskimen, Northeastern Kazakhstan.[30] The idea behind the fuel bank is that any IAEA member can request access to this supply as a last resort. This provides IAEA members with a safety net for energy production from nuclear sources, ensuring that electricity access is not disrupted due to the inaccessibility of an essential raw material.

This LEU bank was developed using a US$ 150 million fund with contributions from IAEA members, including the United States (US$ 49 million), the European Union (US$ 24.4 million), the State of Kuwait (US $10 million), the United Arab Emirates (US$ 10 million) and Norway (US $5 million).

The LEU bank has been operational since October 2019 and operates under the responsibility of the authorities for safety, security and safeguards in Kazakhstan. Thanks to this venture, Kazakhstan has been able to expand its export potential, as uranium supplies held by the LEU bank are purchased domestically.[31]

How can Aid for Trade help unlock opportunities in the nuclear value chain?

Possibilities to use Aid for Trade to help developing economies and LDCs participation participate in nuclear global value chains include:

Minerals and metals: Copper, nickel and chromium are examples of minerals and metals that are required for the deployment of nuclear infrastructure (IEA, 2022h). Energy generation also requires a continuous supply of uranium, a mineral that is extracted in many developing economies and LDCs. As the demand for uranium rises with increased nuclear use, it provides developing economies and LDCs with export opportunities. An example of international cooperation to develop uranium infrastructure in Kazakhstan is provided in Box 4.14.

Goods: Examples of equipment used in nuclear power plants include control rods, moderators, coolants, steam generators and pressurisers.[32] Aid for Trade can help with value chain integration by facilitating technology transfers and by providing financial support to help economies establish these manufacturing capacities.

Services: The deployment of nuclear energy generation requires a workforce that has the capacity to handle specialized tasks requiring substantial skill and expertise. Undertaking a nuclear power programme therefore represents a long-term investment in human capital.[33] According to the World Nuclear Association (WNA),[34] nuclear power plants can operate for over 60 years, creating well-paid jobs for people from a range of fields and educational backgrounds. Investments can also create a spillover effect that benefits other sectors. Leveraging Aid for Trade to develop skills and expertise in nuclear technology can thus create positive feedback loops that benefit trade potential in other sectors.

Endnotes

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